Public Good Provision and Ancillary Benefits: The Case of Climate Agreements

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Abstract

Several studies found ancillary benefits of the provision of public goods to be of considerable size. If these additional private benefits were noticed, they would imply not only higher cooperative but also non-cooperative provision levels. However, beyond these largely undisputed important quantitative effects, there would be qualitative and strategic implications associated with ancillary benefits: public policy would no longer be a pure but an impure public good. In this paper, we investigate these implications in a setting of non-cooperative coalition formation in the context of climate change. In particular, we address the following question. Would ancillary benefits if they were taken in consideration increase participation in international climate agreements and raise the success of these treaties in welfare terms?

Keywords: ancillary benefits, impure public goods, coalition formation, game theory, climate policy

JEL classifications: C72, H87, Q54

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1. Introduction

Already Musgrave (1959: 13) stressed: “Certain public wants may fall on the border line between private and social wants, where the exclusion principle can be applied to part of the benefits gained but not to all.” Such impure public goods raised much attention in economics. For instance, Andreoni (1989, 1998) applies the basic approach developed by Cornes and Sandler (1984) to the field of philanthropy and shows that neutrality of income redistribution (the neutrality theorem by Warr (1982, 1983)) does not hold in the case of impure public goods. Cornes and Sandler (1994) demonstrate that divergent degrees of substitutability/complementarity of the private and public characteristics of the impure public good lead to quite different comparative static results.

Recently, the inefficiently low provision of impure public goods at an international level receives much attention in the literature. Comparative static analyses based on the model by Cornes and Sandler (1994) are conducted by Rübbelke (2003) who investigates climate policy as well as by Kotchen (2005) who considers environmentally friendly consumption where the public good characteristic is tropical biodiversity. Rübbelke (2003) includes an alternative technology producing the impure public good’s private characteristic independently of the public one,[1] while Kotchen (2005) allows for both, an independent production of the private as well as of the public characteristic.[2] Sandler and Murdoch (1990) study another international policy issue. They consider a system of demand equations for pure and impure public good problems and distinguish between Nash-Cournot and Lindahl behavior. They

1 Löschel and Rübbelke (2009) conduct a related numerical analysis based on climate policy in Germany.

2 Vicary (1997, 2000) investigates different technologies available for raising the level of the public characteristic of the impure public good.

illustrate their technique by estimating military expenditure equations for a sample of ten NATO allies. They find that Nash-Cournot, rather than Lindahl behavior, best characterizes allies' behavior. More importantly, they find that the impure public good specification provides a better fit than the pure public good specification for their model.

Although the analysis of the impact of private characteristics on the non-cooperative and optimal policy levels is important, the analysis of the strategic implications for the prospects of cooperation is still in its infancy. Such implications may affect the willingness of countries to participate in agreements that coordinate internationally the provision of impure public goods.

Also in the climate change context it has been argued that combating global warming generates not only global public benefits by slowing climate change (primary benefits), but also ancillary benefits which are enjoyed privately by the individual climate protecting nations.[3] Whereas the primary benefits of climate policy can be enjoyed globally, the ancillary benefits can only be enjoyed on a local or regional scale (IPCC (1996: 217)).[4] Aunan et al. (2007: 472) point to significant ancillary benefits to China since climate protection efforts will not only cause a reduction in GHG emissions but also reductions in emissions of local/regional pollutants like particles and NO_X-emissions. These (and other) non-GHG-emission reductions – in turn – will improve public health and will increase agricultural yields on a

[3] Ancillary benefits are benefits generated by climate policy that are not derived from the slowing of climate change. Other terms which convey this idea are secondary benefits, co-benefits and spillover benefits (see IPCC (2001) and Markandya and Rübbelke (2004: 489)).

[4] Furthermore, in contrast to primary benefits, ancillary benefits arise almost immediately after the climate protection measure has been accomplished. Krupnick, Burtraw and Markandya (2000: 55) note: "we feel the heart of the analysis of ancillary benefits involves the *here and now* that is relevant to individual policy makers in a national context."

local/regional scale. Similar results illustrating the significance of ancillary benefits in developing countries emerge from studies by, e.g., Rive and Rübbelke (2010) for China, Dessus and O'Connor (2003) for Chile and Bussolo and O'Connor (2001) for India.[5]

Although considered to be of less importance than in developing countries, ancillary benefits in industrialized countries may also be significant. Several studies found that ancillary benefits may exceed the primary benefits from slowing climate change, as Pearce (2000: 523) illustrates. For the US he shows that ancillary benefits are a multiple of primary benefits, in the range between 0.07 and 6.67 (for European studies the range is between 0.98 (UK) and 6.93 (Germany)). An overview of further US studies is provided by Burtraw et al. (2003: 650-673).

As Ekins (1996a: 163, 1996b: 14) illustrates the inclusion of ancillary benefits in cost-benefit analyses will cause a rise in optimal climate policy levels. Moreover, Cornes and Sandler (1984: 595) stress for impure public goods that "the jointly produced private output can serve a privatizing role, not unlike the establishment of property rights". Nevertheless, also for such goods, one should expect sub-optimally low provision levels because of the (remaining) public good part which evokes free-riding incentives.

In other words, were ancillary benefits being noticed by governments, this would call for higher globally optimal abatement levels but this would also be the case in the non-cooperative equilibrium. Because of the gap between optimal and non-cooperative climate protection levels, international coordination would still be

[5] Ancillary benefits of environmental protection in the form of reputational benefits enjoyed by clubs of firms are discussed by van't Veld and Kotchen (2012). Green electricity as an impure public benefit to private households is investigated by Kotchen and Moore (2007).

needed. However, the lack of a global coercive authority prevents the enforcement of an efficient level of global climate protection; countries have to voluntarily negotiate and agree upon such coordination, i.e. they have to form self-enforcing agreements. It is this strategic dimension of ancillary benefits that we are interested in but which has been neglected so far in the literature on impure public good provision, including the application to climate protection. In particular, we address the following question. Would ancillary benefits if they were taken in consideration increase participation in international climate agreements and would this raise the success of these treaties in welfare terms? Our research is immediately related to two approaches. The first approach analyzes for instance the implications of mitigation versus adaptation (e.g. Barrett (2008)) or the link of climate mitigation and R&D of new abatement technologies (e.g. Barrett (2006), Hoel and de Zeeuw (2009)) for the success of self-enforcing international environmental agreements (IEAs). However, their settings imply two strategies and two effects whereas our analysis implies that one strategy (i.e. abatement) has two effects (i.e. a private and a public effect).

The second approach proposed by Pittel and Rübbelke (2008) analyzes the strategic implications of ancillary benefits as we do but restricts attention to only two countries and a simple bi-matrix game. They find that if international negotiations are represented as a chicken game, ancillary benefits tend to have a positive influence on the propensity of countries to participate in an international agreement on climate change.

In this paper, we will investigate the second approach further. We depart from the normal form game in Pittel and Rübbelke (2008) and use a non-cooperative coalition formation game (as the first approach mentioned above does) which has been pioneered by Barrett (1994), Carraro and Siniscalco (1993) and Hoel (1992) and subsequently being continued for instance by Breton et al. (2006), Caparrós et al. (2004), de Zeeuw and Pavlova (2011), Finus et al. (2005) and Osmani and Tol (2009).[6] We investigate three model versions, which have been considered in the literature. We reach quite different and mostly negative conclusions compared to Pittel and Rübbelke (2008). The driving forces are different in the three models. In the first model, ancillary benefits lead to a smaller coalition as they reduce the threshold of countries necessary for an agreement to be profitable. In the other two models, ancillary benefits increase not only abatement and payoffs of coalition members but also of outsiders, which leaves the free-rider incentives mainly unchanged.

In the following, we develop our framework, analyze the size of stable coalitions and evaluate the success of coalition formation in welfare terms for three models in Section 2. Finally, we summarize our main findings in Section 3 and point to possible future research issues.

2. The Model

2.1 Introduction

We consider a two-stage cartel formation game with N countries – which can be regarded as the working horse in the analysis of international environmental agreements since Barrett (1994), Carraro and Siniscalco (1993) and Hoel (1992). In the first stage, countries decide upon membership. Countries that join the coalition are called signatories (with superscript M for members) and those that remain outside are called non-signatories (with superscript NM for non-members) and assumed to act as singletons. Let n denote the number of signatories with N the total number of

[6] A survey of this large body of literature is provided for instance in Carraro (2000) and Finus (2003, 2008). Many applications to international environmental problems are provided in Barrett (2003) and with particular reference to climate change in Endres (2011).

countries, $n \leq N$. In the second stage, signatories coordinate their actions, choosing their abatement levels such as to maximize the aggregate payoff to all signatories.[7] Non-signatories act selfishly and maximize only their own payoff. The payoff function of an individual country is given by

$$(1) \qquad \pi_i = B\left(\sum_{j=1}^{N} q_j\right) + \alpha B(q_i) - C(q_i) \text{ with } \alpha \geq 0$$

where the public good part of benefits, $B(\sum_{j=1}^{N} q_j)$, depends on total abatement, $\sum_{j=1}^{N} q_j$, the private good part of benefits, $\alpha B(q_i)$, as well as abatement cost, $C(q_i)$, depend on individual abatement, q_i.[8] The parameter α measures the weight which ancillary benefits receive in the payoff function of countries. Thus, $\alpha = 0$ corresponds to the standard assumption in the literature on IEAs. For simplicity and mathematical convenience, we assume the same functional form for primary benefits and ancillary benefits. For a similar reason, we assume countries to be ex-ante symmetric, i.e. all have the same payoff function, though depending on whether they are signatories or non-signatories they may receive different payoffs ex-post.[9] These simplifications allow us to concentrate on the general effects of ancillary benefits on the strategic interaction of signing cooperative agreements.

Upon reflection of the objective function in (1) it is worthwhile noting that ancillary benefits cannot only be viewed as an "additional factor" on the benefit side, but,

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7 Alternative assumptions such as modest abatement targets, which may lead to larger stable coalitions have been considered by Finus and Maus (2008). A similar idea, including a negotiation process between different countries has already been proposed by Endres (1997) and later applied to the coalition context by Finus and Rundshagen (1998).

8 As we assume a static payoff function, endogenous technological change cannot be captured by our model. Moreover, links between primary and ancillary benefit are assumed away.

9 This assumption has been made frequently in the literature though it is certainly a simplification. See for instance Yi (1997).

alternatively, as a “reducing factor” on the cost side since both costs and ancillary benefits are ‘private’ to the abating agent (see also Ekins 1996b: 14).[10] In the following, our analysis proceeds along the first interpretation, though the alternative interpretation leads to qualitatively equivalent results.

Given the equilibrium abatement choices in the second stage (which we analyze in more detail in the subsequent subsections), a signatory’s payoff is denoted by $\pi_i^M(n)$ and a non-signatory payoff by $\pi_i^{NM}(n)$ in order to indicate that payoffs will depend on the number of signatories, n. Working back to the first stage, a coalition is said to be stable if it is internally and externally stable:[11]

(2) Internal Stability: $\pi_i^M(n) \geq \pi_i^{NM}(n-1) \;\; \forall\, i \in S$

(3) External Stability: $\pi_i^{NM}(n) > \pi_i^M(n+1) \;\; \forall\, i \notin S$

where S denotes the set of coalition members and where we assume for convenience that in case a non-signatory is indifferent between joining and staying outside the coalition he will join. In some parts of the analysis it will be helpful to work with the stability function introduced by Hoel and Schneider (1997) $\Phi_i(n) = \pi_i^M(n) - \pi_i^{NM}(n-1)$ noticing that $\Phi_i(n) \geq 0$ means internal stability and $\Phi_i(n+1) < 0$ external stability. In other words, if coalition n is internally stable, then coalition $n-1$ is externally unstable and if coalition n is externally stable, then coalition $n+1$ is internally unstable.

10 We owe this point to Catherine Hagem.

11 Alternative stability concepts, which lead to larger stable coalitions, like for instance farsighted stability, have been considered for instance by Osmani and Tol (2009).

Subsequently, we consider specific benefit and cost functions that have been frequently used in the literature as analytical results for general payoff functions cannot be derived.

2.2 Model with Linear Benefit and Cost Functions

The simplest payoff function assumes linear benefit and cost functions, which may almost be regarded as a toy model, though it has received a lot of prominence in the recent literature (e.g. Barrett (2003), Ulph (2004) and Kolstad (2007)). The reason – apart from its simplicity – is that this model version allows generating every stable coalition size which can be related to the benefit-cost ratio from abatement.

Consider the following payoff function where b is a benefit and c a cost parameter:

$$(4) \qquad \pi_i = b\sum_{j=1}^{N} q_j + \alpha b q_i - c q_i \text{ with } b > 0,\ c > 0 \text{ and } \alpha \geq 0.$$

Since only the relation b/c matters, we let $\gamma = b/c$ and rewrite (4):

$$(4)\# \qquad \pi_i^{\#} = \gamma\sum_{j=1}^{N} q_j + \alpha\gamma q_i - q_i \text{ with } \gamma > 0$$

such that $\pi_i^{\#}$ is the payoff per cost unit, some kind of normalized payoff. In this simple model, we can normalize the strategy space $\mathrm{q_i} \in [0,1]$ such that there are essentially only two possible equilibrium strategies: “abate” ($q_i = 1$) or “not abate” ($q_i = 0$) . In order to make this model interesting for the subsequent analysis, we follow the standard assumption in the literature and assume that the social optimum and the Nash equilibrium differ. A sufficient condition for abatement $q_i = 1$ to be an equilibrium choice in the social optimum is

(5) Assumption 1: $\frac{\partial \sum_{j=1}^{N} \pi_j^{\#}}{\partial q_i} = N\gamma + \alpha\gamma - 1 > 0 \Leftrightarrow \gamma > \frac{1}{N+\alpha}$

whereas in the Nash equilibrium no abatement $q_i = 0$ is an equilibrium choice provided

(6) Assumption 2: $\frac{\partial \pi_i^{\#}}{\partial q_i} = \gamma + \alpha\gamma - 1 < 0 \Leftrightarrow \gamma < \frac{1}{1+\alpha}$

holds. Summarizing inequality (5) and (6), this prisoners' dilemma type of incentive structure requires the following range of parameters:

(7) Assumption 1+2: $1/(1+\alpha) > \gamma > 1/(N+\alpha)$.

That is, abatement pays from a global but not from an individual perspective.[12] Then total payoffs in the social optimum are $\Pi^{S\#} = N(N\gamma + \alpha\gamma - 1)$ and in the Nash equilibrium $\Pi^{N\#} = 0$.

Suppose now that a coalition of n signatories forms. Non-signatories, act as singletons, and hence their equilibrium abatement choice is $q_i^{NM} = 0$. For signatories abatement pays, i.e. $q_i^{M} = 1$, provided $\pi_i^{M\#}(n) = n\gamma + \alpha\gamma - 1 \geq 0$ holds which is equivalent to $n \geq 1/\gamma - \alpha$. Suppose this condition holds. In order to test for internal stability, we have to compute the payoff of a signatory that leaves the coalition with n signatories such that $n-1$ signatories are left.

12 In the social optimum, the unit cost of abatement is smaller than the global benefits which it generates (inequality (5)) whereas in the Nash equilibrium the unit cost is larger than the individual benefits (inequality (6)). With respect to inequality (6) this means that we assume ancillary benefits to be not so large to overcome the prisoners' dilemma.

Consider first the possibility that the $n-1$ signatories continue to abate because $\pi_i^{M\#}(n-1)=(n-1)\gamma+\alpha\gamma-1\geq 0$ (though the free-riders will not abate as this is the equilibrium choice for singletons) which is equivalent to $n-1\geq {1}/{\gamma}-\alpha$. Then the free-rider receives a payoff of $\pi_i^{NM\#}(n-1)=(n-1)\gamma$. Compared to $\pi_i^{M\#}(n)$, the free-rider receives γ units of benefits less from global abatement, receives no ancillary benefits but also faces no abatement costs as he chooses now $q_i^{NM}=0$ instead of $q_i^{M}=1$. Internal stability requires $\pi_i^{M\#}(n)=n\gamma+\alpha\gamma-1\geq$ $(n-1)\gamma=\pi_i^{NM\#}(n-1)$ or $\gamma>\dfrac{1}{1+\alpha}$ which we ruled out by Assumption 2 in (6).

Consider now the second possibility that signatories switch from abatement to no abatement once a signatory leaves as abatement is no longer profitable for $n-1$ signatories because $\pi_i^{M\#}(n-1)=(n-1)\gamma+\alpha\gamma-1<0$ or $n-1<{1}/{\gamma}-\alpha$. Then $\pi_i^{NM\#}(n-1)=0$ and internal stability requires $\pi_i^{M\#}(n)=n\gamma+\alpha\gamma-1\geq$ $0=\pi_i^{NM\#}(n-1)$ which is equivalent to $n\geq\dfrac{1}{\gamma}-\alpha$. This condition holds by our initial assumption made above, namely that abatement is profitable for the coalition in the first place. Hence, it is the second possibility that defines an internally stable coalition. Letting $n=n^*$, then internal stability requires

(8) $$n^*\geq\frac{1}{\gamma}-\alpha \text{ and } n^*-1<\frac{1}{\gamma}-\alpha \ .$$

In other words, n^* is the largest integer of the relation $1/\gamma-\alpha$, i.e. $n^*=I(1/\gamma-\alpha)$. For any $n>n^*$, signatories would continue to abate after one signatory has left their coalition, which cannot be an equilibrium as argued above. For any $n<n^*$ signatories

would not abate in the first place (as abatement is not profitable) and hence no coalition would form. It is easily checked that n^* is also the only coalition which is externally stable and hence stable.

Thus, in this model, the driving force is a strong threshold effect with $n = n^*$ the break-even point of profitability. The lower the benefit-cost ratio $\gamma = b/c$, the more countries are required to make a coalition profitable (i.e. larger threshold) and hence the larger will be the size of the stable coalition, n^*. Most importantly, because ancillary benefit increase the benefits (or reduce abatement costs), the threshold will be smaller the larger α and hence the smaller will be the coalition size n^*. Consequently, in this model, ancillary benefits reduce the equilibrium size of the stable coalition or at best leave it unchanged (depending on the exact value of γ as n^* is an integer value).

Total payoff in the coalition equilibrium is given by $\Pi^C = n^* \pi_i^M(n^*) + (N - n^*)\pi_i^{NM}(n^*)$ and hence $\Pi^{C\#} = n^*(N\gamma + \alpha\gamma - 1)$ in this model. In order to evaluate the success of coalition formation in welfare terms, it seems sensible to use a relative welfare measure. This is to avoid measuring a welfare effect which is only due to an additional term in the payoff function whenever $\alpha > 0$. Hence, we use the "closing the gap index", which is one possible relative measure as suggested by Eyckmans and Finus (2006):[13]

(9) $$CGI := \frac{\Pi^{C\#} - \Pi^{N\#}}{\Pi^{S\#} - \Pi^{N\#}}$$

[13] For an application of this index in the context of regional fisheries management and a more extensive discussion, see Pintassilgo et al. (2010).

with $1 \geq CGI \geq 0$. Substituting $n^* = I(1/\gamma - \alpha)$ into $\Pi^{C\#}$, and using $\Pi^{S\#}$ and $\Pi^{N\#}$ as computed above, we find:

(10) $$CGI = \frac{n^*}{N}.$$

Thus, anything else being equal, the closing the gap index decreases with the number of players involved in the externality problem, N. This result reflects the public good nature of global environmental problems and is well-known from other models. Moreover, noting that $n^* = I(1/\gamma - \alpha)$, CGI (weakly) decreases in α. Thus, the negative impact of α on the relative welfare measure is due to the negative impact on the coalition size. Hence, ancillary benefits do not improve but may only have a negative impact on our relative performance measure. As we will see, this negative conclusion will not change much in the subsequent models.

Despite being skeptical about absolute welfare measures, we would like to mention for completeness that in absolute terms the conclusion is less negative because

(11) $$\frac{\partial \Pi^{C\#}(\alpha)}{\partial \alpha} = 2 - N\gamma - 2\alpha\gamma$$

which could be positive if N, γ and/or α are sufficiently small.[14]

2.3 Model with Linear Benefit and Quadratic Cost Functions

Consider the following payoff function which has been considered for instance in Botteon and Carraro (1997), Barrett (2006) and Finus and Maus (2008), though without the ancillary benefit part:

[14] For the derivation, we approximate $n^* = I(1/\gamma - \alpha)$ by $n^* = 1/\gamma - \alpha$.

(12) $\pi_i = b\sum_{j=1}^{N} q_j + \alpha b q_i - \frac{c}{2} q_i^2$ with $b > 0$, $c > 0$ and $\alpha \geq 0$.

Also for this model only the relation b/c matters, and hence we let $\gamma = b/c$ and rewrite (12):

(12)# $\pi_i^{\#} = \gamma\sum_{j=1}^{N} q_j + \alpha\gamma q_i - \frac{1}{2} q_i^2$ with $\gamma > 0$.

The first order conditions of signatories read $n\gamma + \alpha\gamma - q_i^M = 0$ and for non-signatories $\gamma + \alpha\gamma - q_i^{NM} = 0$, assuming an interior solution and denoting abatement of signatories with superscript M (members) and abatement of non-signatories with superscript NM (non-members). Hence, $q_i^M(n) = (n+\alpha)\gamma$ and $q_i^{NM} = (1+\alpha)\gamma$ and total abatement is given by $Q^C(n) = nq_i^M(n) + (N-n)q_i^{NM} = \gamma(n^2 + N + N\alpha - n)$. If one member leaves the coalition, $q_i^M(n-1) = (n-1+\alpha)\gamma$, $q_i^{NM} = (1+\alpha)\gamma$ and $Q^C(n-1) = \gamma(n^2 + N + N\alpha + 2 - 3n)$. Substitution of these abatement levels into the payoff function gives

$$\pi_i^{M\#}(n) = \frac{1}{2}\gamma^2(n^2 + 2N + 2N\alpha - 2n + \alpha^2),$$

(13) $$\pi_i^{NM\#}(n) = \frac{1}{2}\gamma^2(2n^2 + 2N + 2N\alpha - 2n + \alpha^2 - 1),$$

$$\pi_i^{NM\#}(n-1) = \frac{1}{2}\gamma^2(2n^2 + 2N + 2N\alpha - 6n + 3 + \alpha^2) .$$

Computation of the stability function $\Phi_i(n) = \pi_i^{M\#}(n) - \pi_i^{NM\#}(n-1)$ shows that $\Phi_i(n) \geq 0$ for $n \in \{2,3\}$ and $\Phi_i(n+1) < 0$ for $n \geq 3$ irrespective of α and hence $n^* = 3$. Thus, in this model, ancillary benefits have no impact on the size of the stable coalition. The intuition (which can be confirmed by observing (13)) is that in this model ancillary benefits increase payoffs of signatories, $\pi_i^{M\#}(n)$, by exactly the same amount as the payoffs of non-signatories if one member has left the coalition, $\pi_i^{NM\#}(n-1)$, and hence the incentive to leave or join the coalition remains unchanged. In other words, the drop in benefits (benefits from global abatement and ancillary benefits) and the drop in abatement costs when leaving a coalition become larger with increasing α, but by the same factor.

We can now compute the global payoff in the coalition equilibrium $\Pi^{C\#} = n^* \pi_i^{M\#}(n^*) + (N - n^*)\pi_i^{NM\#}(n^*)$ by using $n^* = 3$ and find: $\Pi^{C\#} = \frac{1}{2}\gamma^2(11N + 2N^2 + 2N^2\alpha + N\alpha^2 - 24)$. Moreover, the global payoff in the social optimum is $N \cdot \pi_i^{M\#}(n)$, substituting N for n in $\pi_i^{M\#}(n)$. Similarly, the global payoff in the Nash equilibrium is $N \cdot \pi_i^{NM\#}(n)$, setting $n = 1$ in $\pi_i^{NM\#}(n)$. We find for the closing the gap index:

$$(14) \qquad CGI = \frac{12(N-2)}{N(N-1)^2}$$

which is positive but smaller than 1 if $N > 3$ because then the grand coalition is not stable ($n^* < N$). Again, it is straightforward to show that $\partial CGI / \partial N < 0$ provided $N > 3$. Hence, as in the first model (Section 2.2), the coalition improves upon the non-cooperative outcome but achieves only little if the number of countries which suffer from the externality is large. Most importantly, in this model ancillary benefits have no impact on the relative measure of the success of coalition formation. Roughly speaking, all payoffs just change by some factor related to α and, as just argued above, the coalition size does not change for the same reason. Hence, not only stability but also the relative performance in welfare terms is unaffected by ancillary benefits.

Of course, if we measured success in absolute terms, conclusions would be brighter: as the equilibrium coalition size does not change through ancillary benefits, equilibrium abatement increases for signatories and non-signatories in α, ancillary benefits receive a positive weight in countries' payoff function and payoff functions are strictly concave in abatement, $\partial \Pi^{C\#} / \partial \alpha > 0$ holds. However, this positive absolute effect is almost implied by the nature of ancillary benefits and has been pointed out in the Introduction in terms of the Nash equilibrium and the social optimum. This positive effect could only be upset in the context of coalition formation if the equilibrium coalition size were smaller with ancillary benefits as this was the case in the first model.

Compared to the previous model we may conclude that ancillary benefits have at least not a negative effect on the coalition size and the relative welfare measure, but it also cannot be called a breakthrough.

2.4 Model with Quadratic Benefit and Quadratic Cost Functions

Consider the following payoff function:

(15) $$\pi_i = b\left(a\sum_{j=1}^{N} q_j - \frac{1}{2}\left(\sum_{j=1}^{N} q_j\right)^2\right) + \alpha b\left(aq_i - \frac{1}{2}q_i^2\right) - \frac{c}{2}q_i^2 \text{ with } b > 0,\ c > 0 \text{ and } \alpha \geq 0 .$$

This payoff function is essentially the same as in Barrett (1994), Diamantoudi and Sartzetakis (2006) and Rubio and Ulph (2006) though they assume $\alpha = 0$.[15] Since this

[15] Different from Barrett (1994), Diamantoudi and Sartzetakis (2006) and Rubio and Ulph (2006) we do not assume Stackelberg leadership of signatories to be consistent with the

model is far messier in terms of derivations than the previous models, we sketch here only the main arguments of the analysis and relegate the details to the appendix.

The first thing to notice is that marginal benefits from global abatement are positive if and only if total abatement is smaller than a and marginal benefits from ancillary benefits are positive if and only if individual abatement is smaller than a. Hence, in order to ensure interior solutions, it suffices to ensure that total abatement in the social optimum is smaller than a for which a sufficient condition is:

(16) Assumption 3: $\dfrac{1}{(N-1)\gamma} \geq \alpha$ with $\gamma = b/c$.

as argued in the Appendix. In a next step, we analyze the stability function, which we write $\Phi_i(n,\Gamma) = \pi_i^{M\#}(n,\Gamma) - \pi_i^{NM\#}(n-1,\Gamma)$ with Γ being a set of parameters, comprising α, $\gamma = b/c$ and N. It turns out that stability does not depend on the benefit parameter a (see (15)). Not surprisingly for $N = 2$, $\Phi_i(2,\Gamma) > 0$, i.e. the grand coalition is stable. In order to analyze the more interesting case of $N \geq 3$, we first show that $\partial\Phi_i(n,\Gamma)/\partial N < 0$ (and $\partial^2\Phi_i(n,\Gamma)/\partial N^2 < 0$). That is, with an increasing number of coalition members, it becomes more difficult to establish stability for a given number of signatories, n. Hence, in order to test whether $\Phi_i(n,\Gamma)$ can be positive for $n > 2$, we substitute $N = 3$ and $n = 3$ into the stability function and find $\Phi_i(3,\Gamma) < 0$. Hence, we can conclude that there cannot be a stable coalition larger than 2. This finding probably goes back to Carraro and Siniscalco

previous models where Stackelberg leadership would make no difference due to dominant strategies. See Finus (2003). Note that Diamantoudi and Sartzetakis (2006) and Rubio and Ulph (2006) specify their model in terms of emissions which requires to observe constraints as to ensure non-negative emissions. An easy way to get around this problem in our setting is to assume that initial emissions are sufficiently large such that abatement can never exceed initial emissions. It easy to check that equilibrium abatement will never be negative in our model.

(1991).[16] The new and interesting part is that this also holds for ancillary benefits for any α defined in the range in (16).

In a next step, we set $\alpha = 0$ and $n = 2$ in the stability function but make no further assumptions, i.e. $\Phi_i(n = 2, \alpha = 0, \gamma, N)$. We establish that for $0 \le \gamma \le \bar{\gamma}(N) \le 1$ $\Phi_i(n = 2, \alpha = 0, \gamma, N) \ge 0$ where $\bar{\gamma}(N)$ is an upper bound which decreases in N, $\partial\bar{\gamma}(N)/\partial N < 0$. That is, with an increasing number of players N, the range of the parameter γ for which internal stability can be guaranteed for two signatories decreases.

Now we let $\alpha \ge 0$ in the stability function, $\Phi_i(n = 2, \alpha, \gamma, N)$, and show that $\Phi_i(n = 2, \alpha, \gamma, N) \ge 0$ if $\alpha > \Psi(\gamma, N)$ where $\Psi(\gamma, N)$ is defined in equation (A14) in the appendix. Since α is bounded from above as spelled out in (16), we get:

(17) $$\frac{1}{(N-1)\gamma} \ge \alpha \ge \Psi(\gamma, N) \text{ with } \gamma = b/c$$

such that ancillary benefits can make a difference. For $\gamma = \bar{\gamma}(N)$ it can be shown that there exists an α satisfying this inequality. However, the upper bound of α in (17), $1/((N-1)\gamma)$, decreases in γ and N and the lower bound of α, $\Psi(\gamma, N)$, increases in γ and N. Thus, for a given N, we can only slightly increase γ above $\bar{\gamma}(N)$ such that α can still satisfy condition (17). With increasing N this possibility diminishes further.

For instance, recall that we denote the upper bound of γ without ancillary benefits by $\bar{\gamma}(N)$. Define $\bar{\gamma}(N, \alpha)$ such that for $0 \le \gamma \le \bar{\gamma}(N, \alpha)$ $\Phi_i(n = 2, \alpha, \gamma, N) \ge 0$ and

[16] Note that for the Stackelberg assumption, larger stable coalitions could form. See Barrett (1994), Diamantoudi and Sartzetakis (2006) and Rubio and Ulph (2006).

notice that $\overline{\gamma}(N,\alpha)$ increases in α. Denoting the upper bound of $\overline{\gamma}(N,\alpha)$ with ancillary benefits by $\overline{\gamma}^{\alpha}(N)$ by inserting the highest possible value of α in $\overline{\gamma}(N,\alpha)$ which is the left-hand term in (17), we have $\overline{\gamma}^{\alpha}(N) > \overline{\gamma}(N)$ and find for instance for $N = 3$: $\overline{\gamma}^{\alpha}(3) = 0.59$ but only $\overline{\gamma}(3) = 0.41$ without ancillary benefits. However, already for $N = 7$: $\overline{\gamma}^{\alpha}(7) = 0.08$, which is only slightly above $\overline{\gamma}(7) = 0.07$ without ancillary benefits. Thus, the possible extension of the parameter range of γ for which a coalition of two players is stable with ancillary benefits tends to zero for a sufficiently large number of players.

Even more interesting is that one can show that for $N \geq 4$ the closing the gap index CGI, our relative welfare measure as defined in (9), decreases in α for $0 \leq \gamma \leq \overline{\gamma}(N) \leq 1$. This is the parameter range for which a two player coalition would be stable even without ancillary benefits. Thus, it is only for $\overline{\gamma}(N) < \gamma \leq \overline{\gamma}(N,\alpha)$ where no coalition would be stable without ancillary benefits and hence $CGI = 0$ where ancillary benefits can make a difference as $CGI > 0$. However, as pointed out above, with increasing N the difference between $\overline{\gamma}(N,\alpha)$ and $\overline{\gamma}(N)$ shrinks and is almost zero already for $N = 10$.[17]

Taken together, for this model the effect of ancillary benefits is mixed but also not very encouraging. First of all, ancillary benefits cannot expand the coalition to more than 2 signatories which is the upper limit without ancillary benefits. Second, for the parameter range of the benefit-cost parameter γ for which a coalition of two signatories is stable without ancillary benefits, an increasing weight α of ancillary benefits

[17] Again, like in the second model, and not surprisingly, if we measured performance in absolute terms, then ancillary benefits would increase equilibrium abatement and global welfare in the coalition equilibrium for the same reasons mentioned in Section 2.3.

has a negative impact on the relative performance measured as the closing the gap index. Third, in a few instances, ancillary benefits can expand the range of the benefit-cost parameter for which a two player coalition is stable. This expansion is negligible if the total number of players is sufficiently large.

3. Summary and Conclusions

Ancillary benefits have attracted much attention in climate change research and are regularly found to be of significant size. The IPCC (2007: 623) stresses the importance of ancillary benefits in the design of air pollution and energy security policies and the rise in rural employment. The “efficiency-raising impact” of an inclusion of ancillary benefits in cost-benefit analyses has been highlighted recurrently. Efficient climate protection levels would rise considerably if ancillary benefits were included.

Whereas this prediction is straightforward, it is less clear how the privatizing effect of ancillary benefits, if noticed and considered by actors, would affect the strategic interplay between actors and in particular the prospects of cooperation. Intuitively, one would expect that taking ancillary benefits into account will alleviate free-riding incentives and hence will raise the attractiveness of participation in international agreements to slow climate change. However, this intuition was not confirmed in our strategic setting of non-cooperative coalition formation. We found that ancillary benefits have a neutral or negative impact on the size of stable coalitions and the relative success of coalition formation measured in welfare terms. Only in the model with quadratic benefit and quadratic cost functions could ancillary benefits expand the range of the benefit-cost parameter for which a two player coalition can be stable, though this occurs only in a few instances. However, even then the expansion appeared to be small if the total number of players is sufficiently large.

The conclusion which can be drawn from these results is that although ancillary benefits provide additional incentives to protect the climate, they will not raise the likelihood of an efficient global agreement on climate change to come about. The rationale behind this result is that countries taking the private ancillary benefits to a greater extent into account will undertake more emission reduction, irrespective of an international agreement. The relative importance of an international agreement for climate protection is reduced since the privatizing effect of ancillary benefits already provides incentives for protection in a non-cooperative setting. Hence, though ancillary benefits provide an additional incentive to participate and to raise abatement contributions, they also provide an additional incentive to leave the agreement.

As mentioned in the Introduction, ancillary benefits are not only important in the environmental context but in many other instances in economics. Hence, many public goods are in fact impure public goods. Consequently, though our model made explicit reference to climate change, the qualitative conclusions carry over to other problems as long as the provision of impure public goods is voluntary (i.e. is not provided by the government and/or not enforced by a central authority) and features not only public benefits but also some private benefits (Cornes and Sandler (1996)).

Scope for future research is offered by exploring the influence of technological progress on the provision level of impure public good models. Dynamic settings might be especially helpful in this context.[18] For instance, Corradini et al. (2011) recently modelled R&D-investment decisions and emissions abatement in a dynamic theoretical framework in which the knowledge stock is considered to be an impure public good.

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[18] Bahn and Leach (2008) consider ancillary effects of climate policy due to the reduction of SO_2 emissions in an overlapping generation model.

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Appendix

For payoff function (15) in the text, the first order condition of a non-signatory and signatory (assuming an interior solution), respectively, are given by

(A1) $$ab - b\left(Q^{NM} + Q^{M}\right) + \alpha\left(ab - b\left(\frac{Q^{NM}}{N-n}\right)\right) - c\left(\frac{Q^{NM}}{N-n}\right) = 0$$

(A2) $$n\left(ab - b\left(Q^{NM} + Q^{M}\right)\right) + \alpha\left(ab - b\left(\frac{Q^{M}}{n}\right)\right) - c\left(\frac{Q^{M}}{n}\right) = 0$$

where we denote total abatement of non-signatories by Q^{NM} and of signatories by Q^{M} with the understanding that total abatement is $Q^{NM} + Q^{M} = (N-n)q_i^{NM} + nq_i^{M}$. Solving (A1) and (A2) simultaneously delivers:

(A3) $$Q^{M} = \frac{abn(nc - bn\alpha N + bn^2\alpha + \alpha bN + \alpha^2 b + \alpha c)}{(\alpha b + c)(\alpha b + bn^2 + bN - bn + c)}$$

(A4) $$Q^{NM} = \frac{ab(N-n)(\alpha^2 b + \alpha b + bn^2\alpha - n\alpha b + \alpha c + c)}{(\alpha b + c)(\alpha b + bn^2 + bN - bn + c)}$$

Computing $q_i^{NM} = Q^{NM}/(N-n)$ and $q_i^{M} = Q^{M}/n$ we find

(A5) $$q_i^{M} - q_i^{NM} = \frac{ab(n-1)(c - \alpha b(N-1))}{(\alpha b + c)(\alpha b + bn^2 + bN - bn + c)}\ .$$

It is easy to show that Assumption 3 in (16) is sufficient that A5 is positive, all individual and global equilibrium abatement levels are positive and smaller than the parameter a such that marginal benefits from global abatement and marginal ancillary benefits from individual abatement are always positive. Moreover, global abatement increases with the coalition size, n.

In a next step we analyze the stability function $\Phi_i(n) = \pi_i^M(n) - \pi_i^{NM}(n-1)$. We find

(A6) $\Phi_i(n,\Gamma) = \pi_i^M(n) - \pi_i^{NM}(n-1) = \dfrac{(n-1)(\alpha bN - 1 - \alpha b)^2(b^2a^2)\bullet D}{E\bullet F\bullet G}$ with

$$D = -(-3 - 4b + n - 2bN + 6bn - 2b^2Nn - 4b^2n^2N - 3b^2n^2 + 2b^2n\alpha N + 2b^2n^3\alpha + b^2n\alpha^2$$

$$+2n^3b^2N + b^2N^2 + 2nbN + nb^2N^2 + 2bn^3 + b^2n^5 + 7b^2n^3 - 5b^2n^4 - 6\alpha b - 8bn^2 + 2n\alpha b$$

$$-8b^2n^2\alpha - 3\alpha^2b^2 - 2\alpha b^2N + 6\alpha b^2n - 4\alpha b^2)$$

$$E = 2(\alpha b + bn^2 - 3bn + 2b + bN + 1)^2,\ F = (\alpha b + bn^2 + bN - bn + 1)^2,\ G = (\alpha b + 1)$$

where E, F and G are positive and hence the denominator is positive. The first three terms in the numerator are also positive. Hence, the sign of $\Phi_i(n,\Gamma)$ depends on the sign of D. We observe that D does not depend on the parameter a and only depends on the relation $\gamma = b/c$. Hence, the sign of D is a function of the parameters α, γ, N and n. Dividing D by c^2, letting $D\# = D/c^2$ and using $\gamma = b/c$, we find

(A7) $\partial D\#/\partial N = -2(n\alpha\gamma + \gamma N + \gamma n^3 - \alpha\gamma + \gamma Nn - \gamma n - 2\gamma n^2 - 1) < 0$

because the term in brackets is positive, noticing that $n \geq 1$. Moreover,

(A8) $\partial^2 D\#/\partial N^2 = -2\gamma(\gamma + \gamma n) < 0$.

Substituting $N = 2$ and $n = 2$ into $D\#$ gives

(A9) $D\#(2,2) = 1 + 4\gamma + 4\alpha\gamma^2 + \alpha^2\gamma^2 + 2\alpha\gamma > 0$.

Substituting $N = 3$ and $n = 3$ into $D\#$ gives

(A10) $D\#(3,3) = -8\gamma(9\gamma + \alpha\gamma + 1) < 0$

and hence we can conclude that for $N \geq 3$ there is no stable coalition of more than 2 signatories. Consequently, it remains to analyze stability for $n = 2$ and $N \geq 3$.

Substituting $n = 2$ into $D\#$ but making no assumptions about N gives

(A11) $\quad D\#(2,\Gamma) = A + B$ with

$A = 1 + \gamma(8 - 2N) + \gamma^2(4N + 4 - 3N^2)$ and $B = \alpha\gamma^2(8 - 2N) + 2\alpha\gamma + \alpha^2\gamma^2$.

We observe that A and B decrease in N and for given α and γ become negative for N sufficiently large. Moreover, $B = 0$ if $\alpha = 0$. Solving $D\#(2,\Gamma)$ for γ, setting $\alpha = 0$, gives

(A12) $\quad \gamma_1 = \dfrac{4 - N + 2\sqrt{3 - 3N + N^2}}{3N^2 - 4N - 4}$ and $\gamma_2 = \dfrac{4 - N - 2\sqrt{3 - 3N + N^2}}{3N^2 - 4N - 4}$

As it can be shown, only the first solution is positive for $N \geq 3$ and hence the relevant one, which we denote by $\overline{\gamma}(N)$ in the text. Since A is concave in γ for $N \geq 3$, we can conclude that $\Phi_i(2,\Gamma) \geq 0$ if $0 \leq \gamma \leq \overline{\gamma}(N)$. It is straightforward to check that $\overline{\gamma}(N) < 1$ and $\partial\overline{\gamma}(N)/\partial N < 0$ for $N \geq 3$.

Investigating B and computing $\partial B/\partial\alpha = 2\gamma + \gamma^2(8 - 2N + 2\alpha)$ reveals that α has clearly a positive influence on stability for $N \in \{3,4\}$. For $N \geq 5$, α must be sufficiently large. Noticing that B, and hence $A + B$, is convex in α if α is sufficiently large, we solve $D\#(2,\Gamma)$ for α and find

(A13) $\quad \alpha_1 = \dfrac{-1 + \gamma N - 4\gamma + 2\sqrt{\gamma^2 N^2 - 3\gamma^2 N + 3\gamma^2}}{\gamma}$ and

$$\alpha_2 = \frac{-1+\gamma N - 4\gamma - 2\sqrt{\gamma^2 N^2 - 3\gamma^2 N + 3\gamma^2}}{\gamma}$$

where only the first solution is positive and hence the relevant one. Hence, observing Assumption 3 in (16) in the text, we get

(A14) $$\frac{1}{(N-1)\gamma} \geq \alpha \geq \frac{-1+\gamma N - 4\gamma + 2\sqrt{\gamma^2 N^2 - 3\gamma^2 N + 3\gamma^2}}{\gamma} = \Psi(\gamma, N).$$

Obviously, $1/((N-1)\gamma)$ decreases in N and γ. For $\Psi(\gamma, N)$ we find

(A15) $$\frac{\partial \Psi(\gamma, N)}{\partial N} = \frac{\sqrt{\gamma^2(3-3N+N^2} + 2\gamma N - 3\gamma}{\sqrt{\gamma^2(3-3N+N^2}} > 0 \text{ and } \frac{\partial \Psi(\gamma, N)}{\partial \gamma} = \frac{1}{\gamma^2} > 0$$

recalling that we assume $N \geq 3$. Hence, with increasing N, the range of α that satisfies (A14) decreases. Moreover, the possibility of increasing γ above $\overline{\gamma}(N)$ to $\overline{\gamma}(N,\alpha)$ is also limited. For instance, using (A12) and (A14), assuming for α the highest possible value, $\alpha = 1/((N-1)\gamma)$, letting $\overline{\gamma}(N, \alpha = 1/((N-1)\gamma)) = \overline{\gamma}^{\alpha}(N)$ we find:

N	3	4	5	6	7	8	9	10
$\overline{\gamma}(N)$	0.41	0.19	0.12	0.09	0.07	0.06	0.05	0.04
$\overline{\gamma}^{\alpha}(N)$	0.59	0.25	0.15	0.11	0.08	0.07	0.06	0.05

Inserting $\overline{\gamma}(N)$ for γ in (A14) shows however that $\frac{1}{(N-1)\gamma} - \Psi(\gamma, N) > 0$ for $N \geq 2$ and hence there always exists an α that satisfies condition (A14) at the limit of $\gamma = \overline{\gamma}(n)$.

Investigating the closing the gap index as defined in (9) in the text for $n = 2$, we find

(A16) $$CGI = \frac{2(\alpha\gamma + \gamma N^2 + 1) \bullet H}{N(\alpha\gamma + 2\gamma + \gamma N + 1)^2 (\alpha\gamma + 1)(N-1)^2}$$ with

$$H = -3\alpha^2\gamma^2 + 2\alpha\gamma^2 N + 2\alpha\gamma^2 N^2 - 2\alpha\gamma^2 N + 4\alpha\gamma N - 6\alpha\gamma + 2\gamma^2 N - \gamma^2 N^2 + 2\gamma N^2 - 2\gamma N + 2N - 3$$

Differentiating CGI with respect to α gives

(A17) $$\frac{\partial CGI}{\partial \alpha} = -\frac{2\gamma^2 (N-2)(\alpha\gamma + \gamma N + 1) \bullet J}{N(\alpha\gamma + 2\gamma + \gamma N + 1)^3 (\alpha\gamma + 1)^2 (N-1)^2}$$ with $J = I + K$,

$I = (2N^2 - N - 6) - 2\gamma(N^2 - N) - \gamma^2 (N^3 + N^2)$ and

$K = \alpha\gamma(4N^2 - 2N - 12) + \alpha^2\gamma^2 (2N^2 - N - 6) - 2\alpha\gamma^2 (N^2 - N)$.

We want to show that $J > 0$ and hence that this derivative is negative. First we concentrate on I. We notice that I is concave in γ. Setting $I = 0$ and solving for γ gives two values of which only one is positive. This value, denoted by $\gamma_\omega(N)$, is given by

(A18) $$\gamma_\omega(N) = \frac{-N + 1 + \sqrt{2N^2 - 9N - 5 + 2N^3}}{N(N+1)}.$$

Thus, $I \geq 0$ if $\gamma \leq \gamma_\omega(N)$. Now it can be shown that $\gamma_\omega(N) > \overline{\gamma}(N)$ for $N \geq 4$ and hence $I > 0$ for $N \geq 4$ and $0 \leq \gamma \leq \overline{\gamma}(N)$, i.e. the parameter range for which a coalition of two players is stable without ancillary benefits. We now turn to K and find:

(A19) $$\frac{\partial K}{\partial \alpha} = \gamma(4N^2 - 2N - 12) + 2\alpha\gamma^2 (2N^2 - N - 6) - 2\gamma^2 (N^2 - N)$$ and

$$\frac{\partial^2 K}{\partial \alpha^2} = 2\gamma^2 (2N^2 - N - 6) .$$

The second derivative is positive for $N \geq 3$ and hence K is convex in α. Consequently, setting the first derivative to zero and solving for α gives us a minimum. We find:

(A20) $$\alpha^* = \frac{2(N^2 - N) - \frac{1}{\gamma}(4N^2 - 2N - 12)}{2(2N^2 - N - 6)}.$$

Now the numerator can only be positive if $1/\gamma$ is sufficiently small. Since we consider the range $0 \leq \gamma \leq \overline{\gamma}(N) < 1$, we test whether the numerator of α^* is positive for $\overline{\gamma}(N)$. It turns out that this is not the case for $N \geq 3$. Consequently, K is minimized for $\alpha = 0$. Then, however, $K = 0$, and hence $J > 0$ and therefore $\partial CGI / \partial \alpha < 0$ for $0 \leq \gamma \leq \overline{\gamma}(N)$. Consequently, we can conclude that α can only have a positive influence on CGI if and only if $\gamma > \overline{\gamma}(N)$ because then no coalition is stable without ancillary benefits.